

# Hollow Electron Beam Collimation Progress

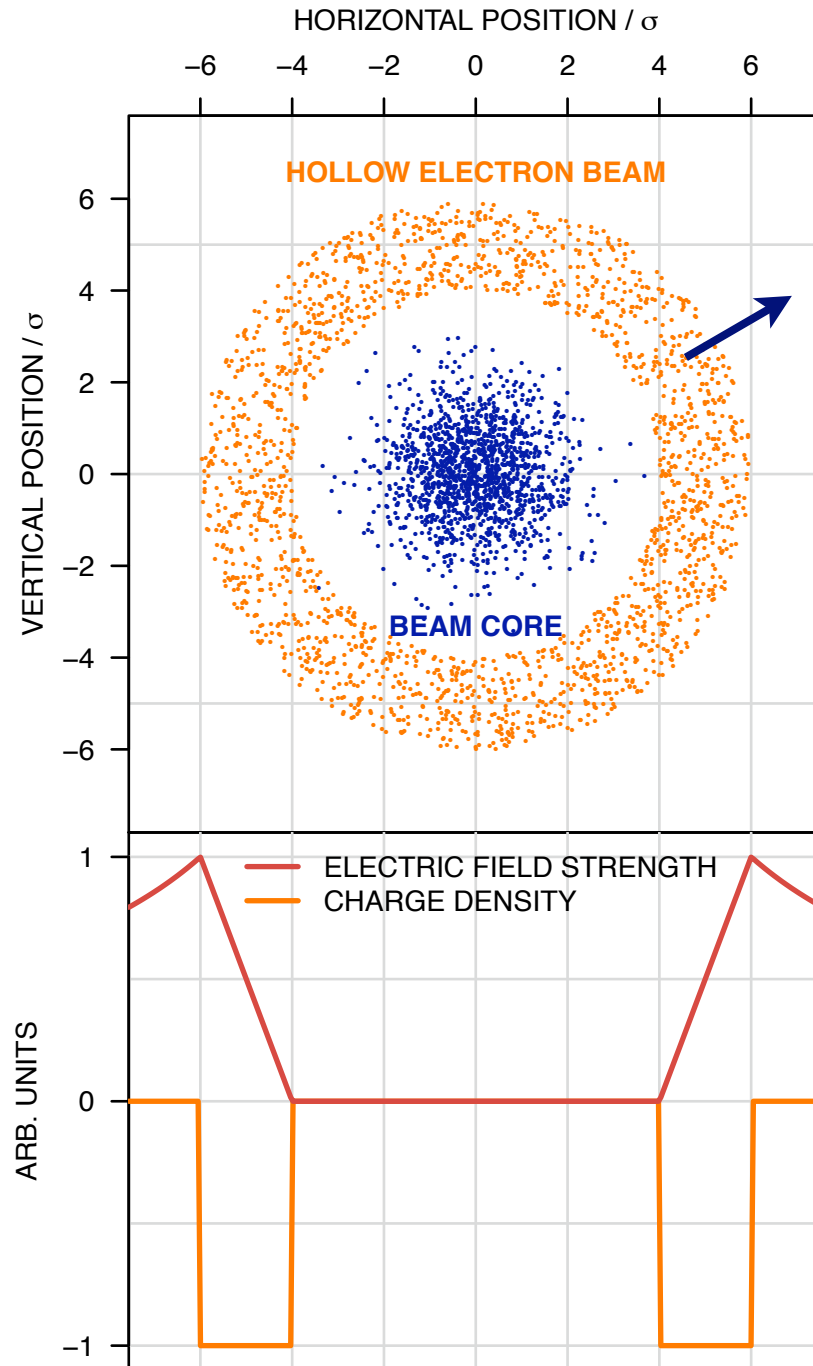
*Is the hollow-beam 'soft scraper' a viable complement to collimation systems for high-intensity machines?*

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G. Saewert, V. Shiltsev, D. Still, L. Vorobiev  
*Fermilab*

Thanks to AD Operations, AD Tevatron, CDF  
and DZero for support and study time

- ▶ Project status
- ▶ Tevatron results
- ▶ Outlook

# Concept of hollow electron beam collimator (HEBC)



Halo experiences nonlinear transverse kicks:

$$\theta_r = \frac{2 I_r L (1 \pm \beta_e \beta_p)}{r \beta_e \beta_p c^2 (B\rho)_p} \left( \frac{1}{4\pi\epsilon_0} \right)$$

About **0.2  $\mu\text{rad}$**   
in TEL2 at 980 GeV

For comparison:  
multiple scattering  
in Tevatron collimators

$$\theta_{\text{rms}} = 17 \mu\text{rad}$$

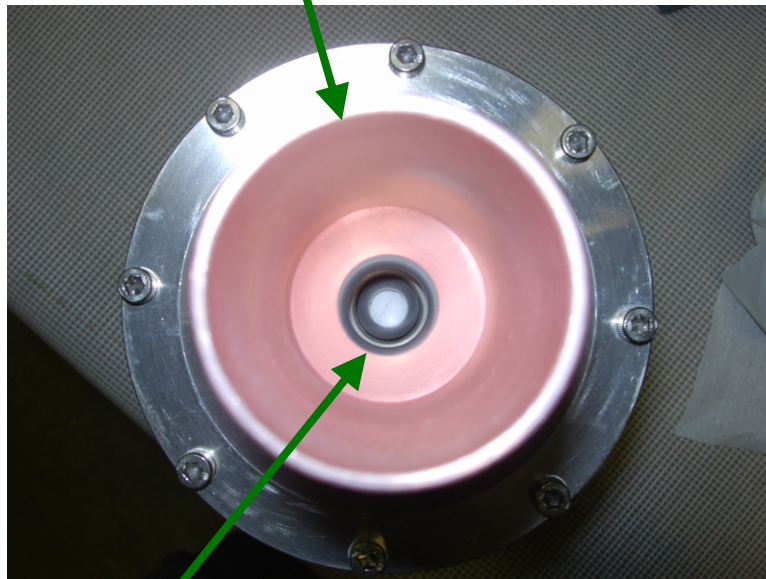
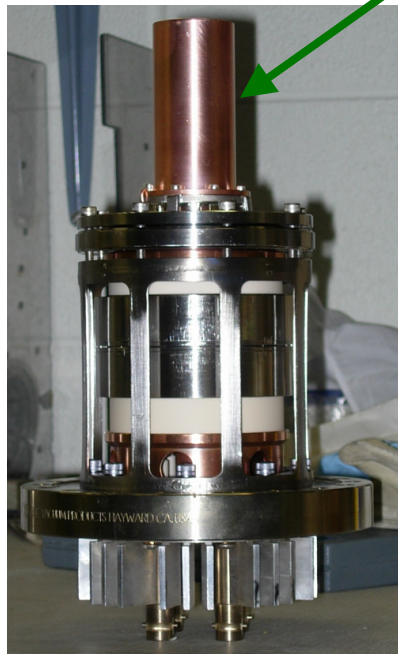
*Shiltsev, BEAMo6, CERN-2007-002*  
*Shiltsev et al., EPACo8*

# The 15-mm hollow electron gun

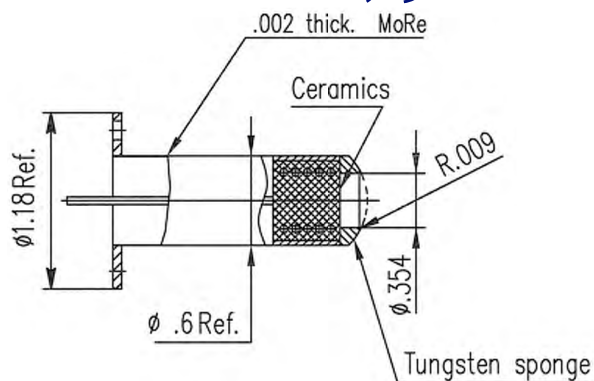
*side view*

Copper anode

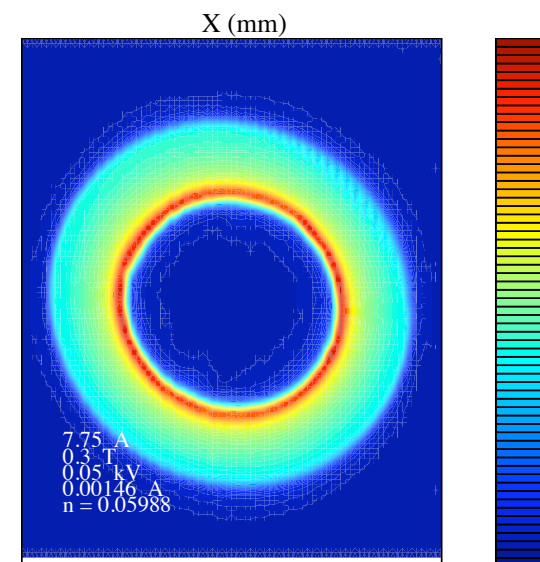
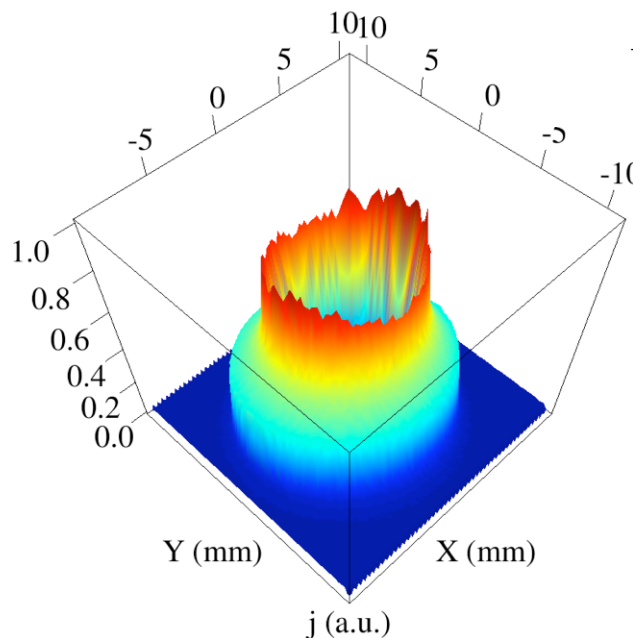
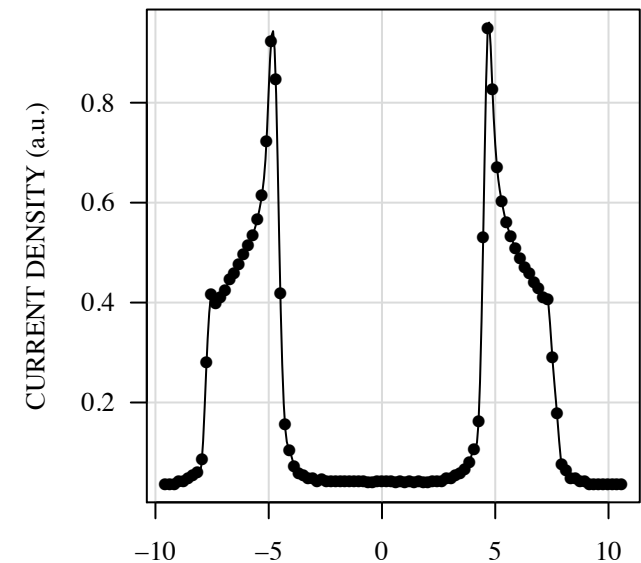
*top view*



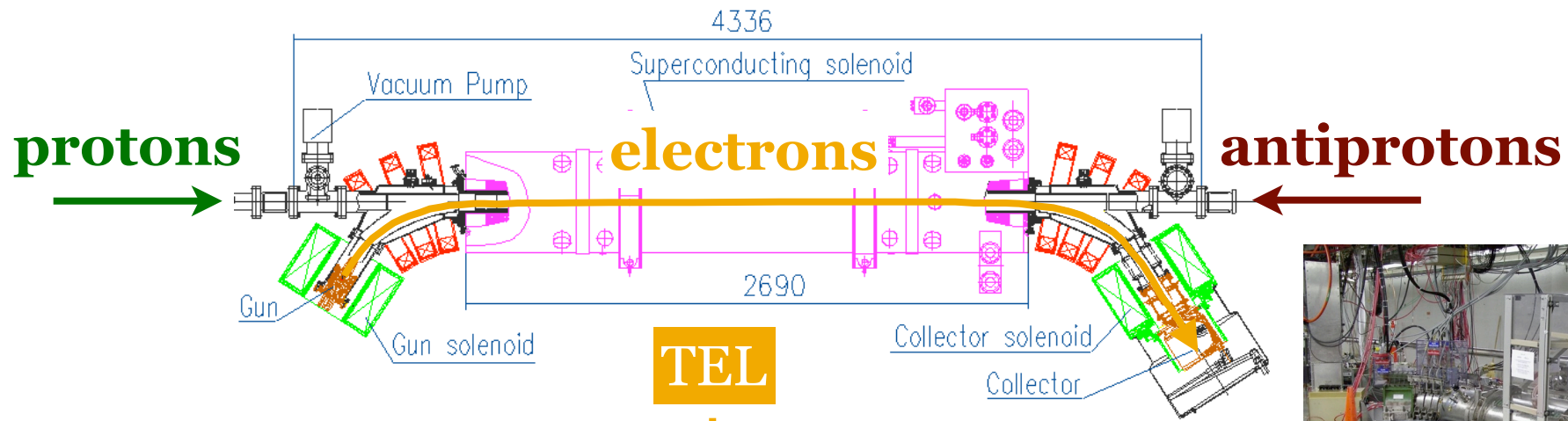
Tungsten dispenser cathode  
with convex surface  
15-mm diameter, 9-mm hole



Yield: **1.1 A** at 4.8 kV  
Profile measurements



# Layout of the beams in the Tevatron

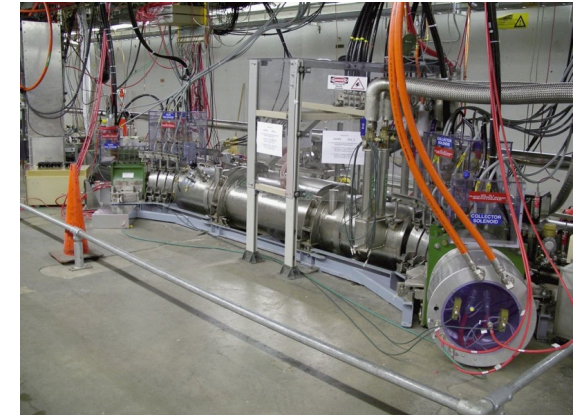
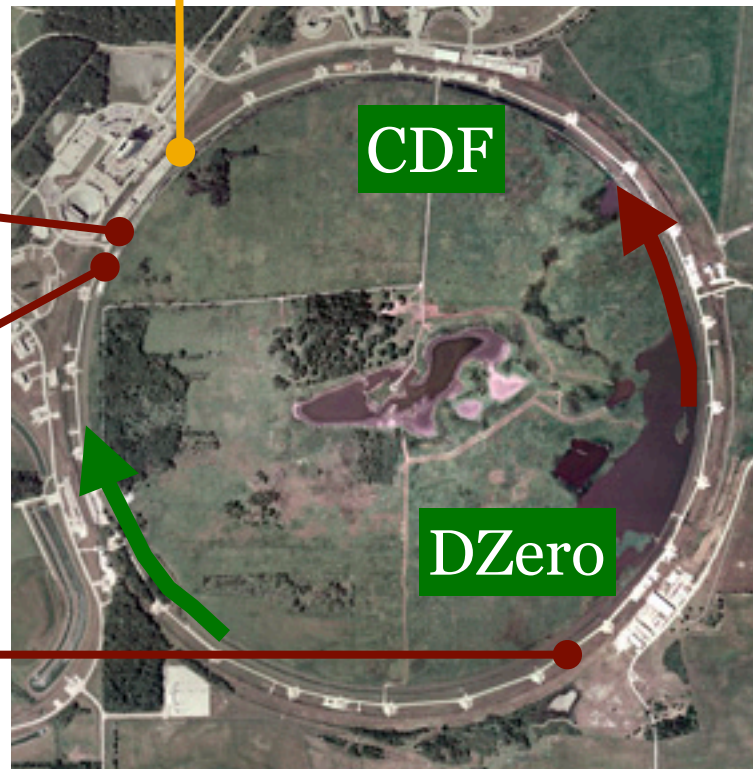


Antiproton collimators:

Primary (F49)

Secondary (F48)

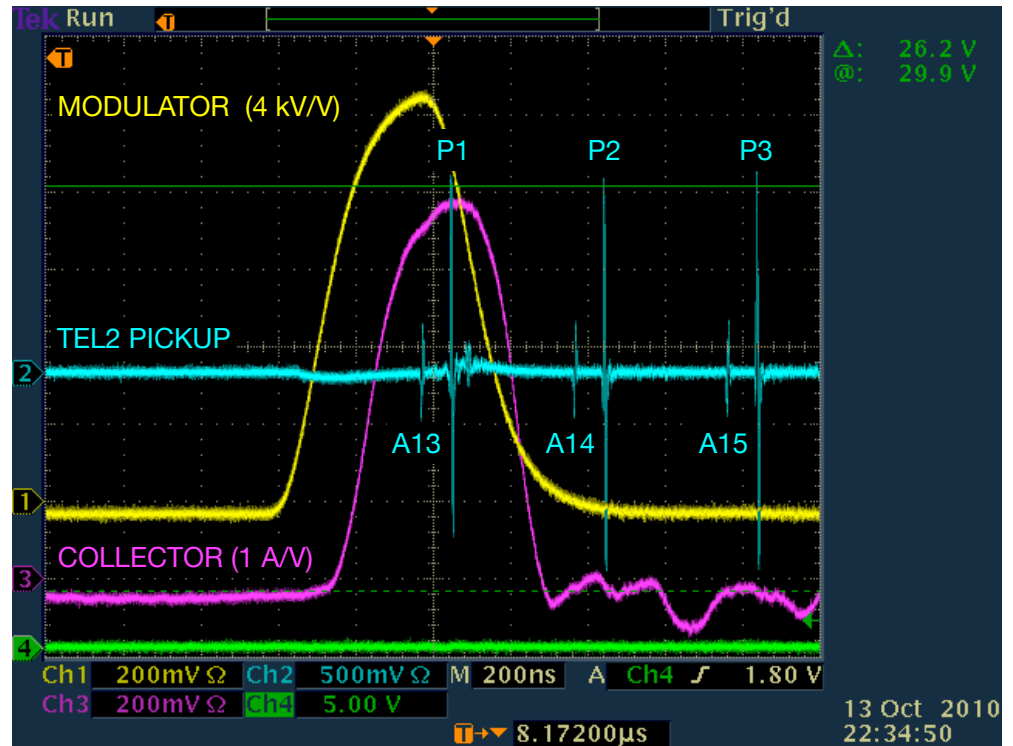
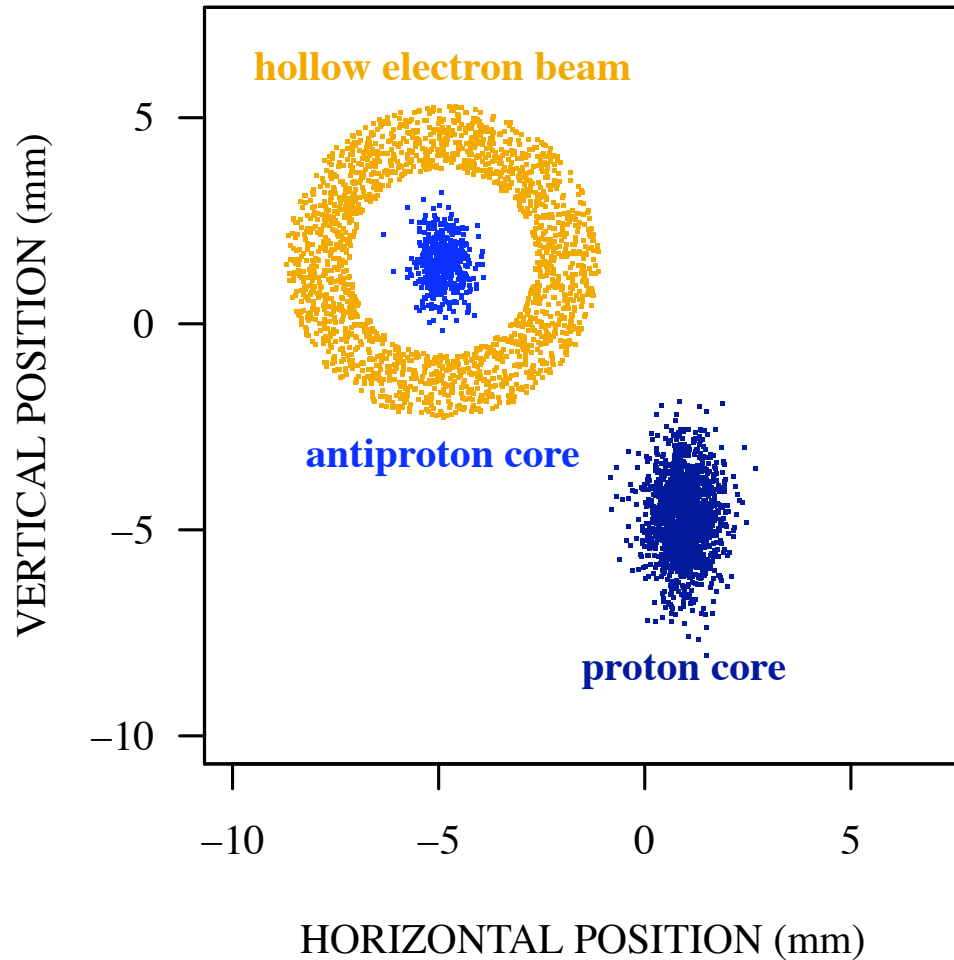
Secondary (D17)



*Tevatron electron lens*

# Layout of the beams in the Tevatron

Transverse separation  
is 9 mm at TEL



Pulsed electron beam  
can be synchronized with  
any group of bunches

# The conventional two-stage collimation system

## ► Goals of collimation:

- reduce beam halo
- direct losses towards absorbers

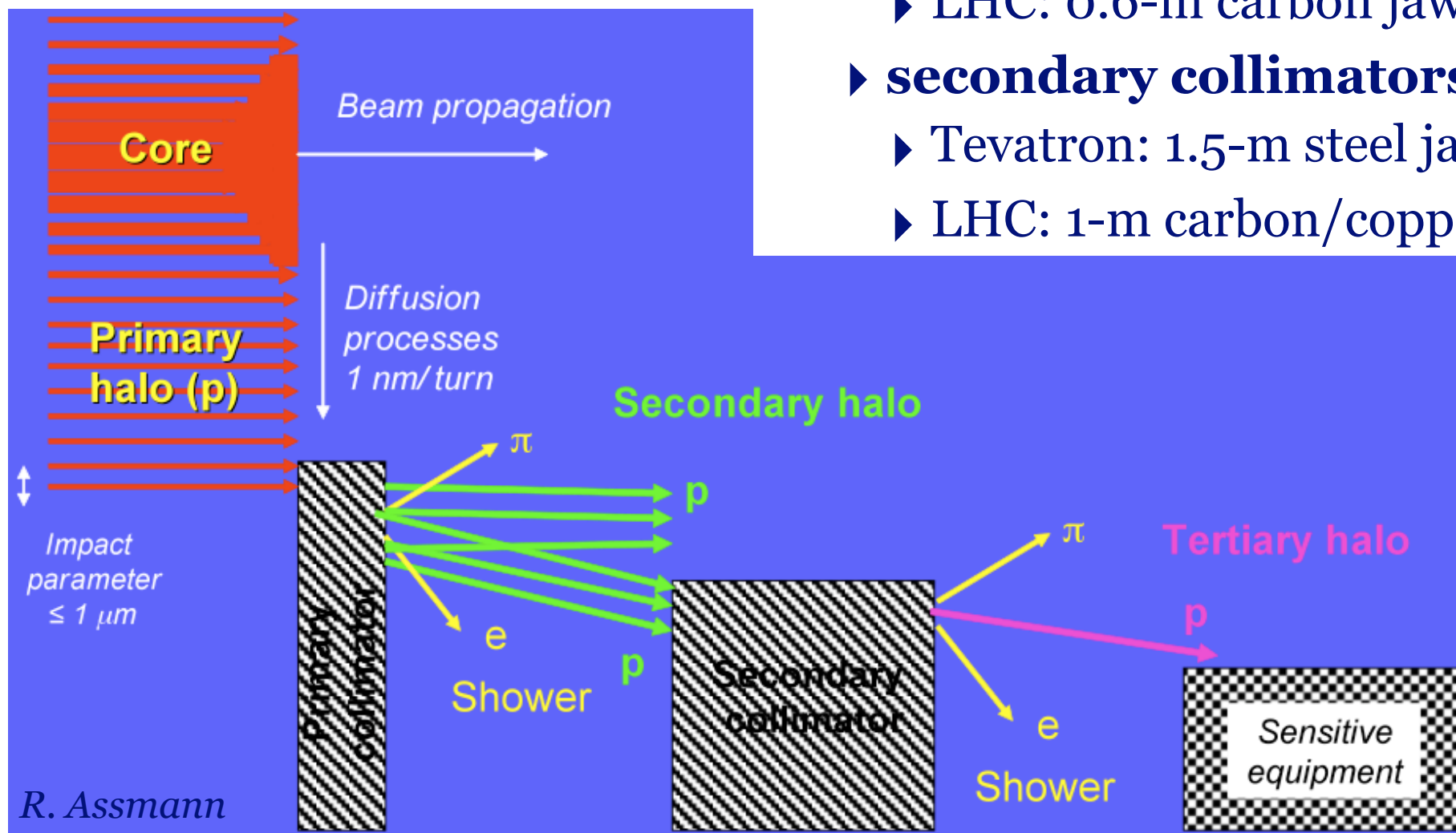
## ► Conventional schemes:

### ► primary collimators

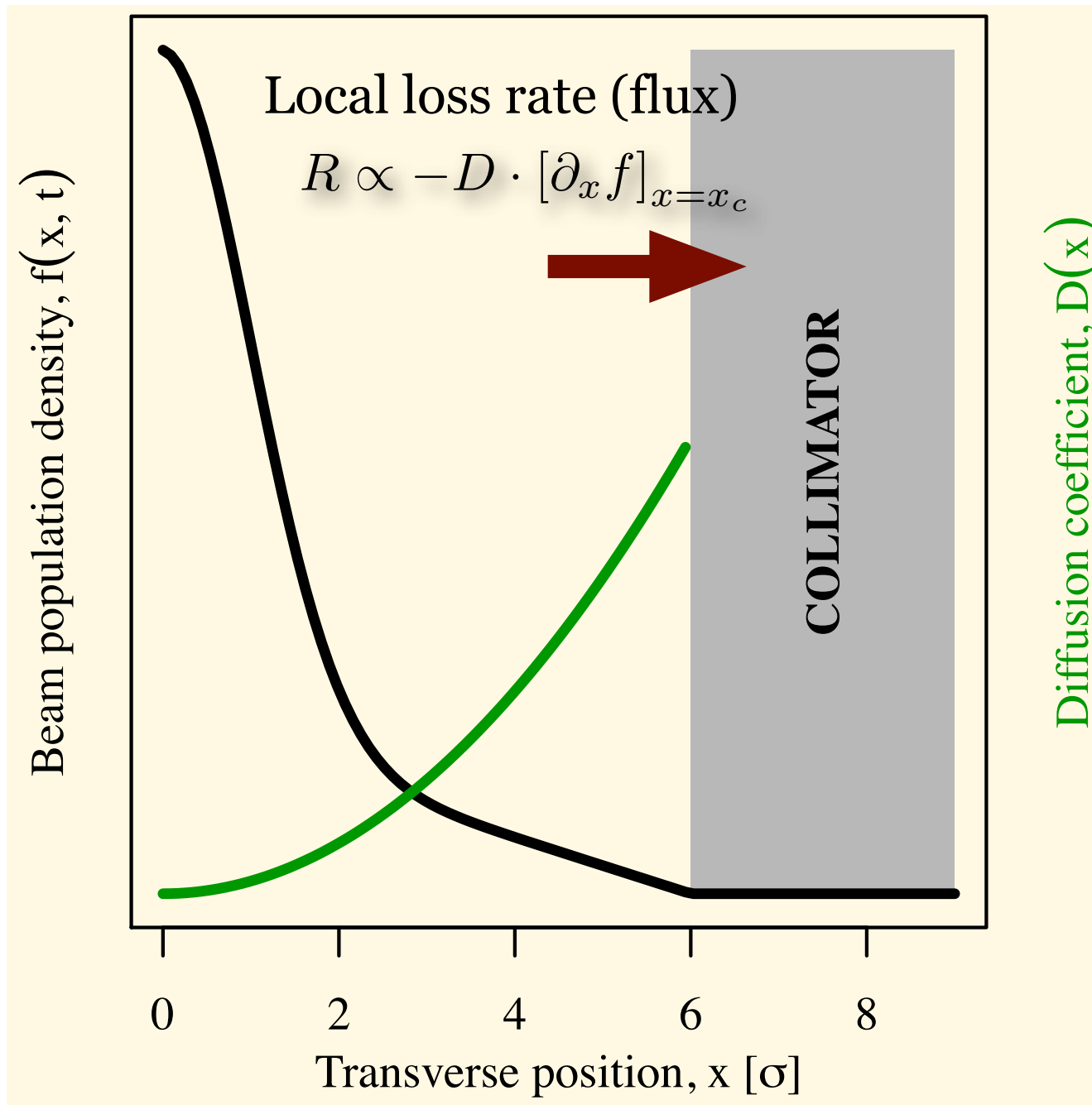
- Tevatron: 5-mm W at  $5\sigma$
- LHC: 0.6-m carbon jaws at  $6\sigma$

### ► secondary collimators

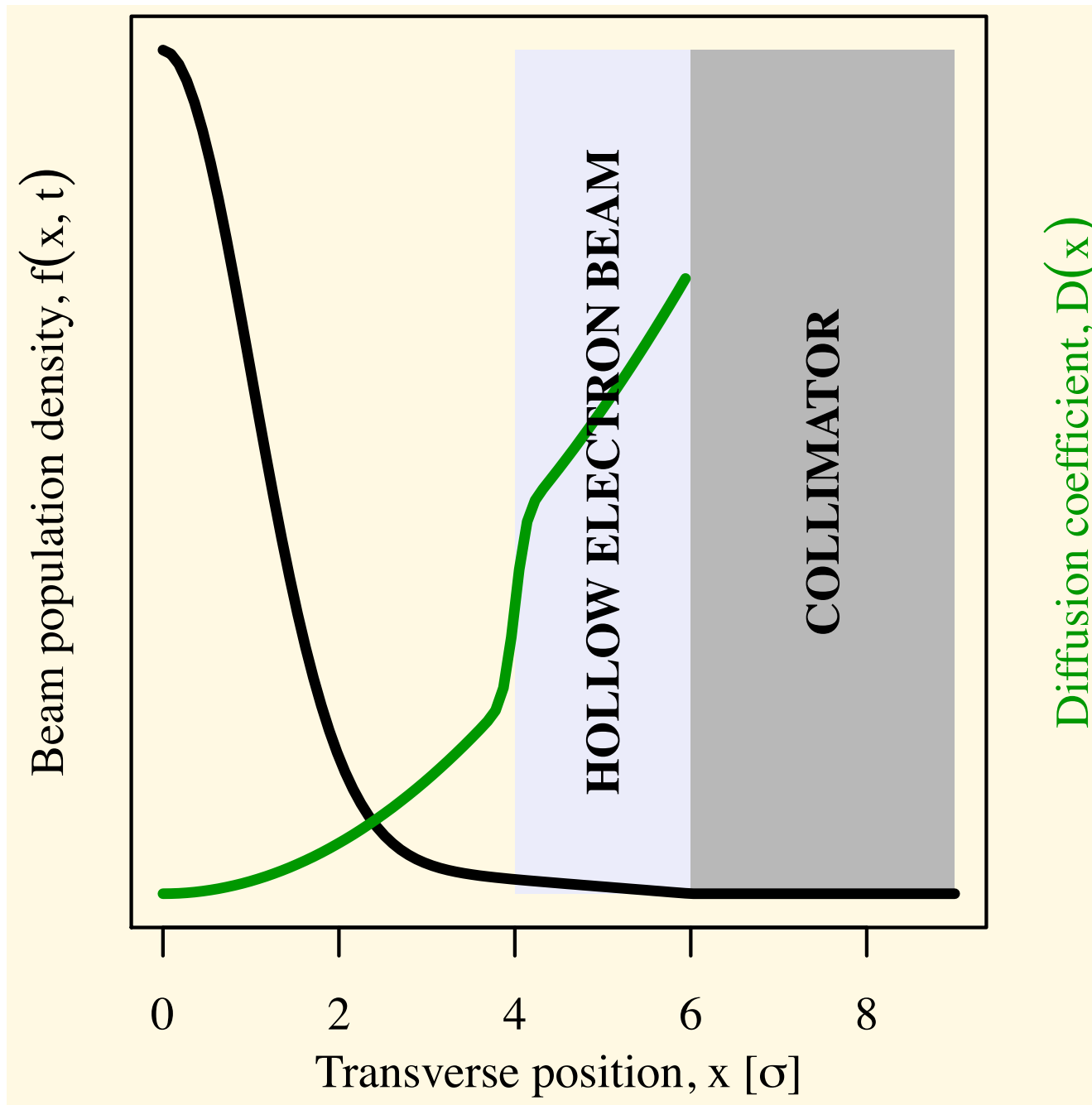
- Tevatron: 1.5-m steel jaws at  $6\sigma$
- LHC: 1-m carbon/copper at  $7\sigma$



# 1-dimensional diffusion cartoon of collimation



# 1-dimensional diffusion cartoon with hollow electron beam



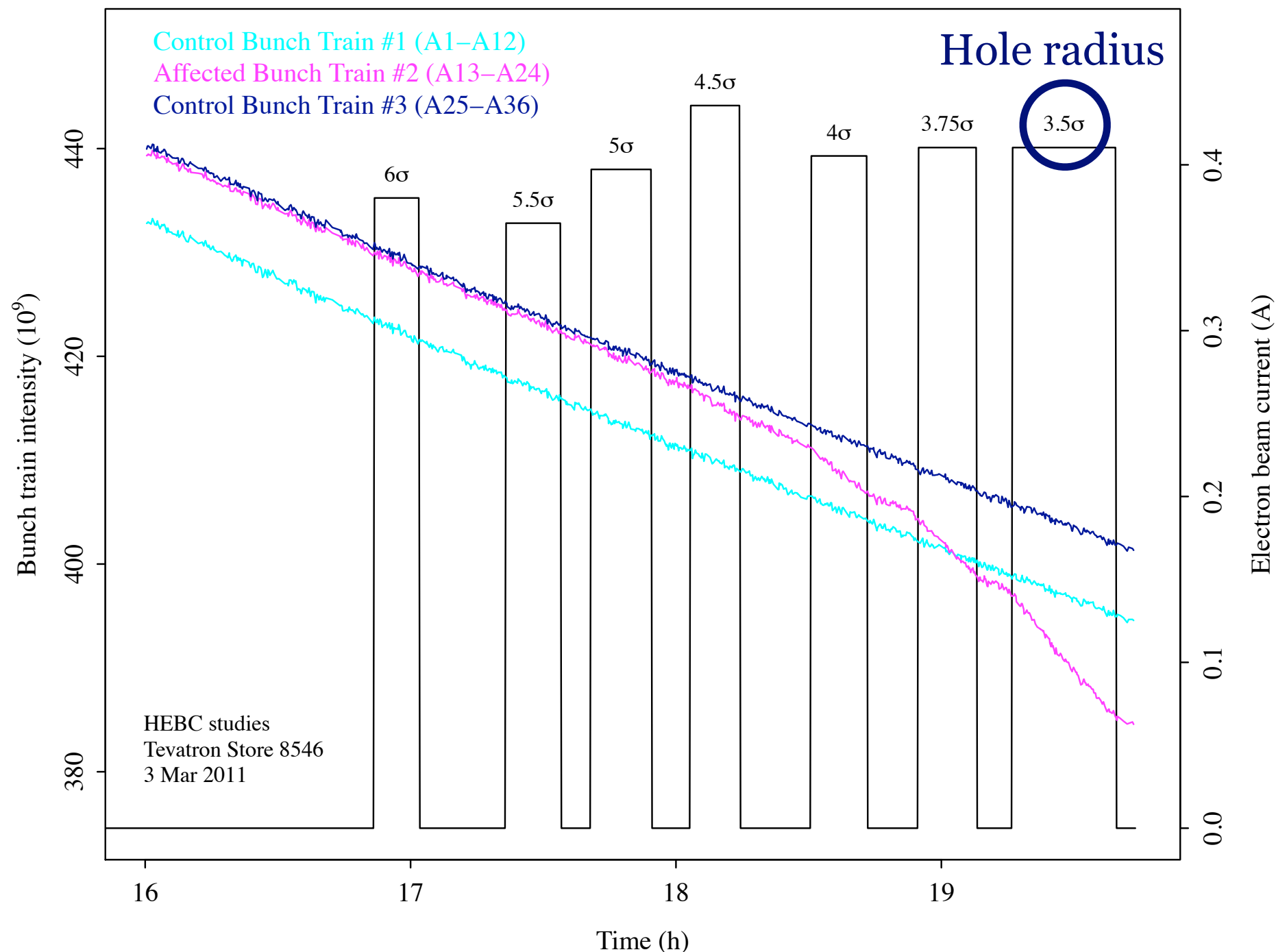
# A good complement to a two-stage system for high intensities?

- ▶ Can be close to or even overlap with the main beam
  - ▶ no material damage
  - ▶ continuously variable strength (“variable thickness”)
- ▶ Works as “soft scraper” by enhancing diffusion
- ▶ Low impedance
- ▶ Resonant excitation is possible (pulsed e-beam)
- ▶ No ion breakup
- ▶ Position control by magnetic fields (no motors or bellows)
- ▶ Established electron-cooling / electron-lens technology
- ▶ Critical beam alignment
- ▶ Control of hollow beam profile
- ▶ Beam stability at high intensity
- ▶ Cost

# Tevatron beam studies

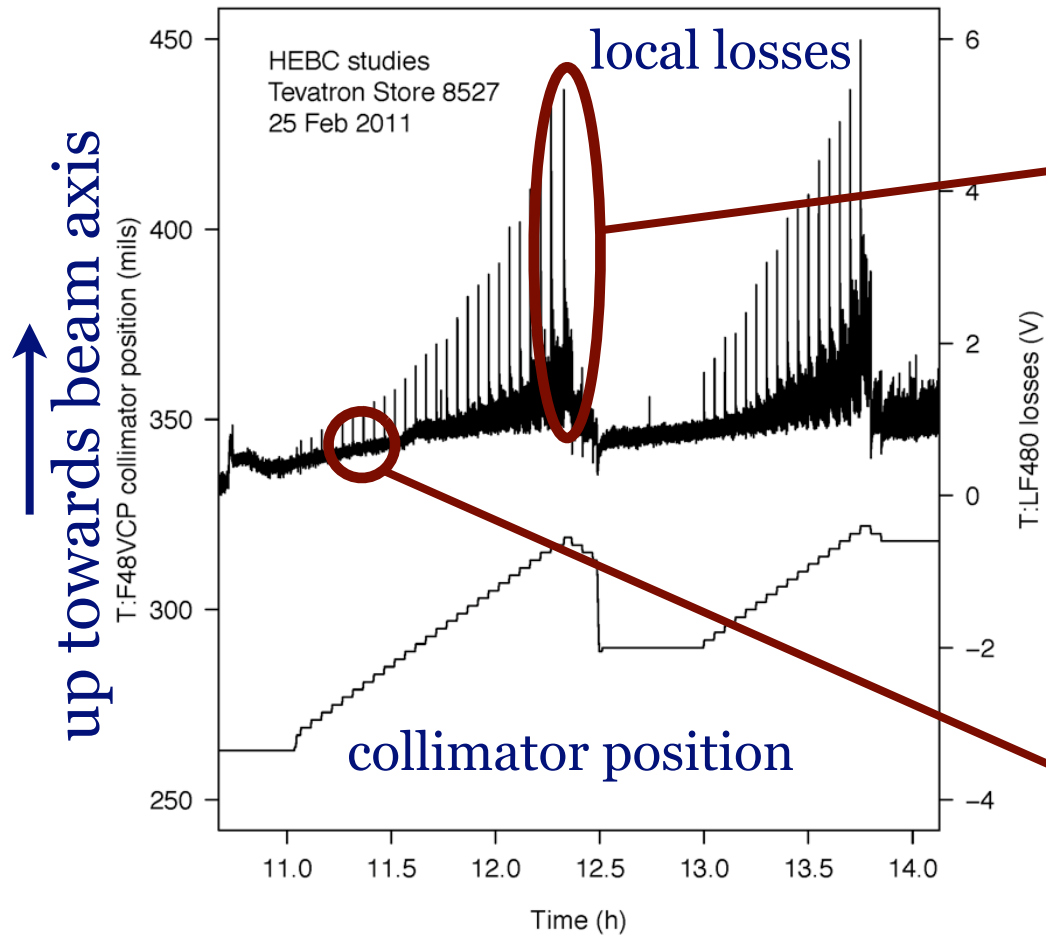
- ▶ Started in October 2010
- ▶ 19 experiments so far: parasitic and dedicated
- ▶ Measured many **observables** vs. main factors: beam current, relative alignment, hole size, pulsing pattern, collimator configuration:
  - ▶ overall particle **removal rate**
  - ▶ **effects on the core** and on unaffected bunches
  - ▶ **removal rate vs. particle amplitude**
  - ▶ enhancement of transverse beam **diffusion**
  - ▶ **collimation efficiency**
  - ▶ **fluctuations** in loss rates
- ▶ Removal rates and halo scraping shown in February
- ▶ A few examples of diffusion and fluctuation effects shown here

# Electrons acting on 1 antiproton bunch train (#2, A13-A24)

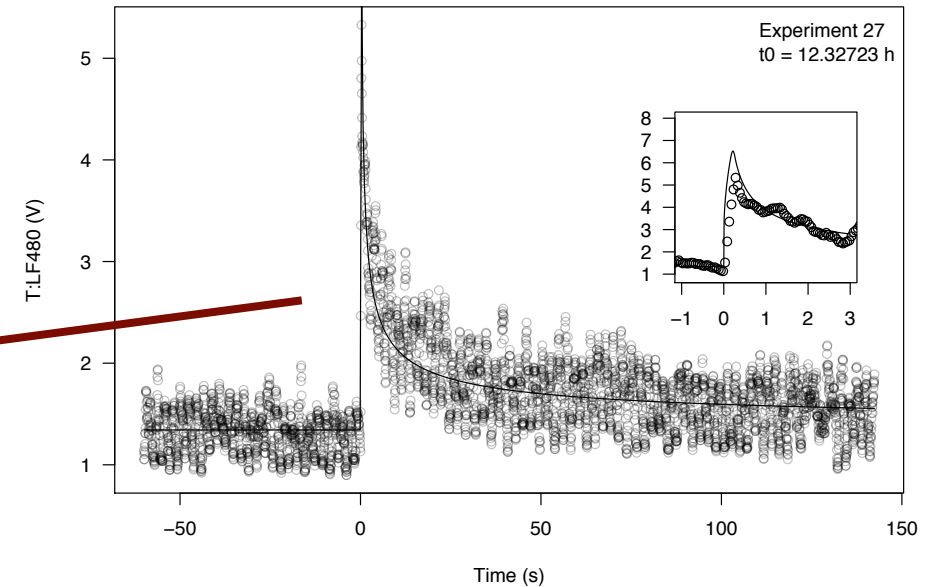


# Diffusion rate vs. amplitude from collimator scans

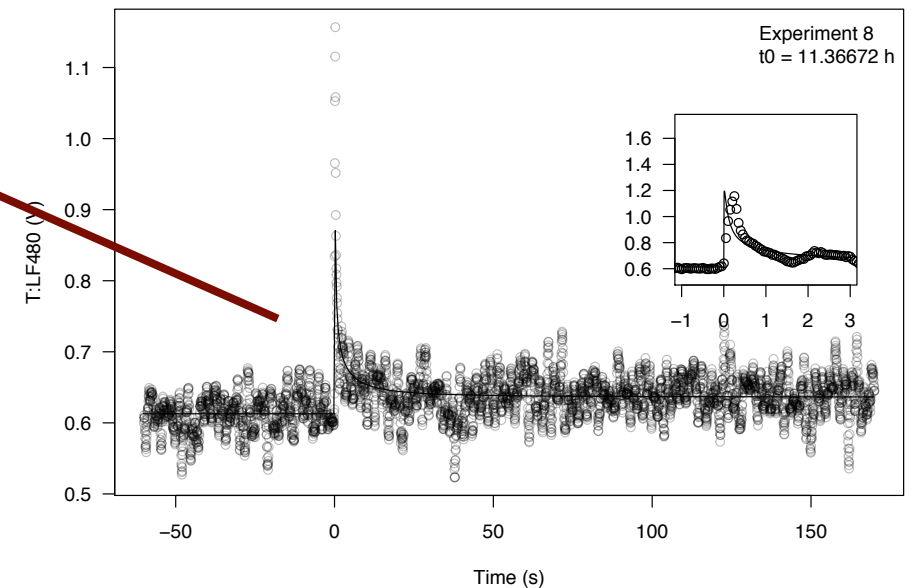
## Vertical secondary collimator scan



Keeping loss spikes below quench limit  
constrains collimator settings



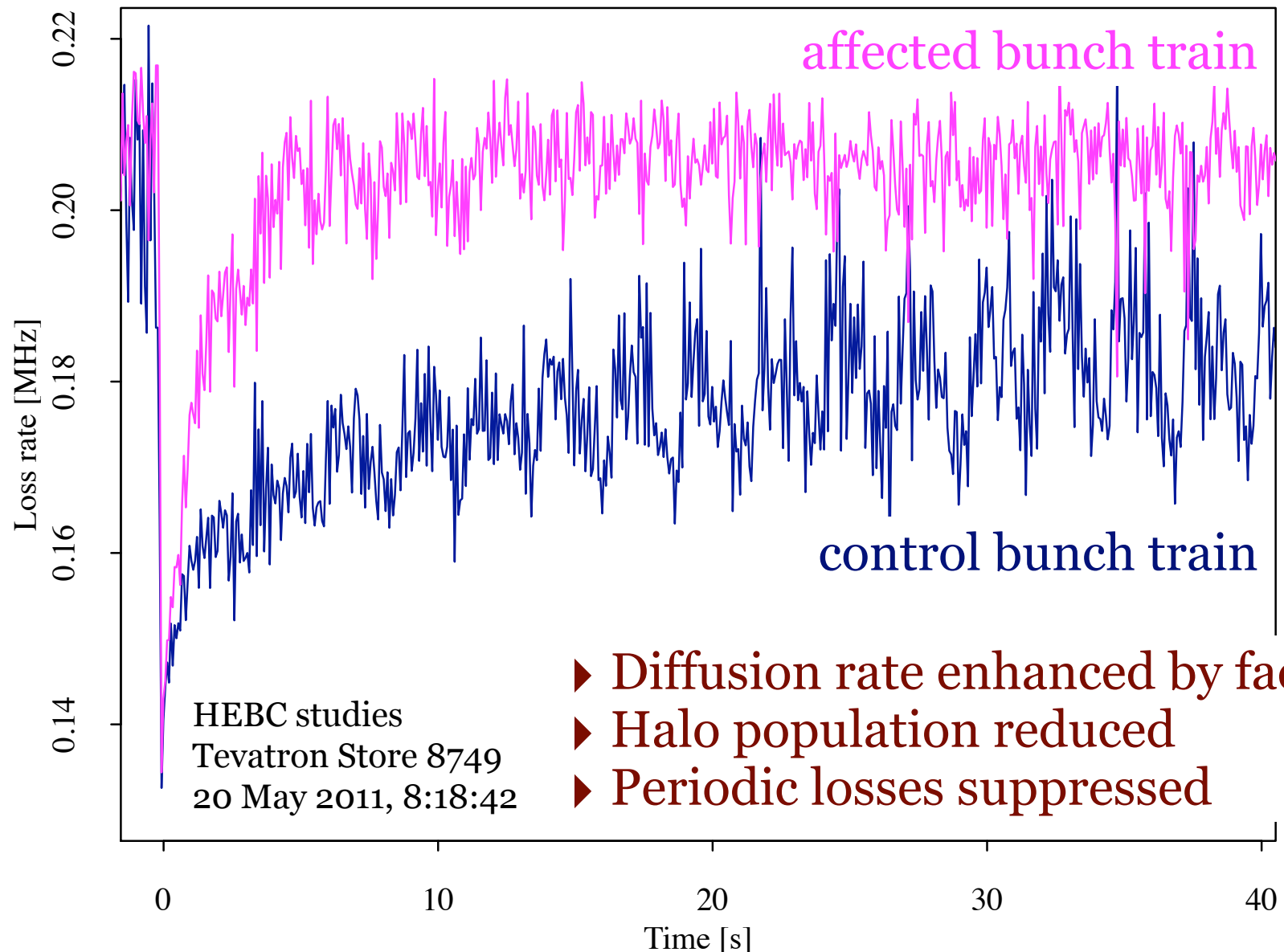
Tails repopulate faster at  
large amplitudes (higher diffusion rate)



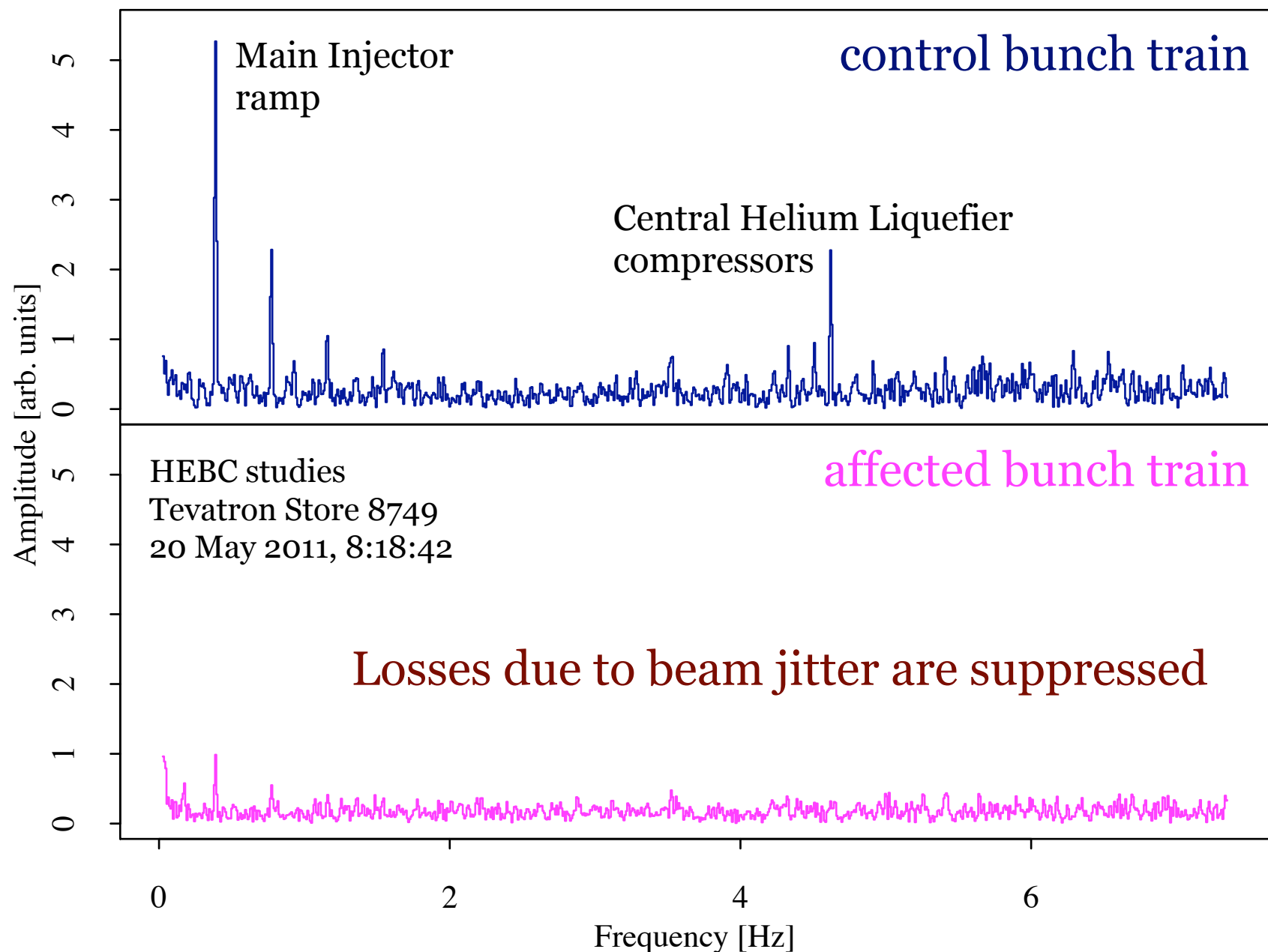
# New gated loss monitors during collimator scan

Electrons (0.9 A) on pbar train #2,  $4.25\sigma$  hole

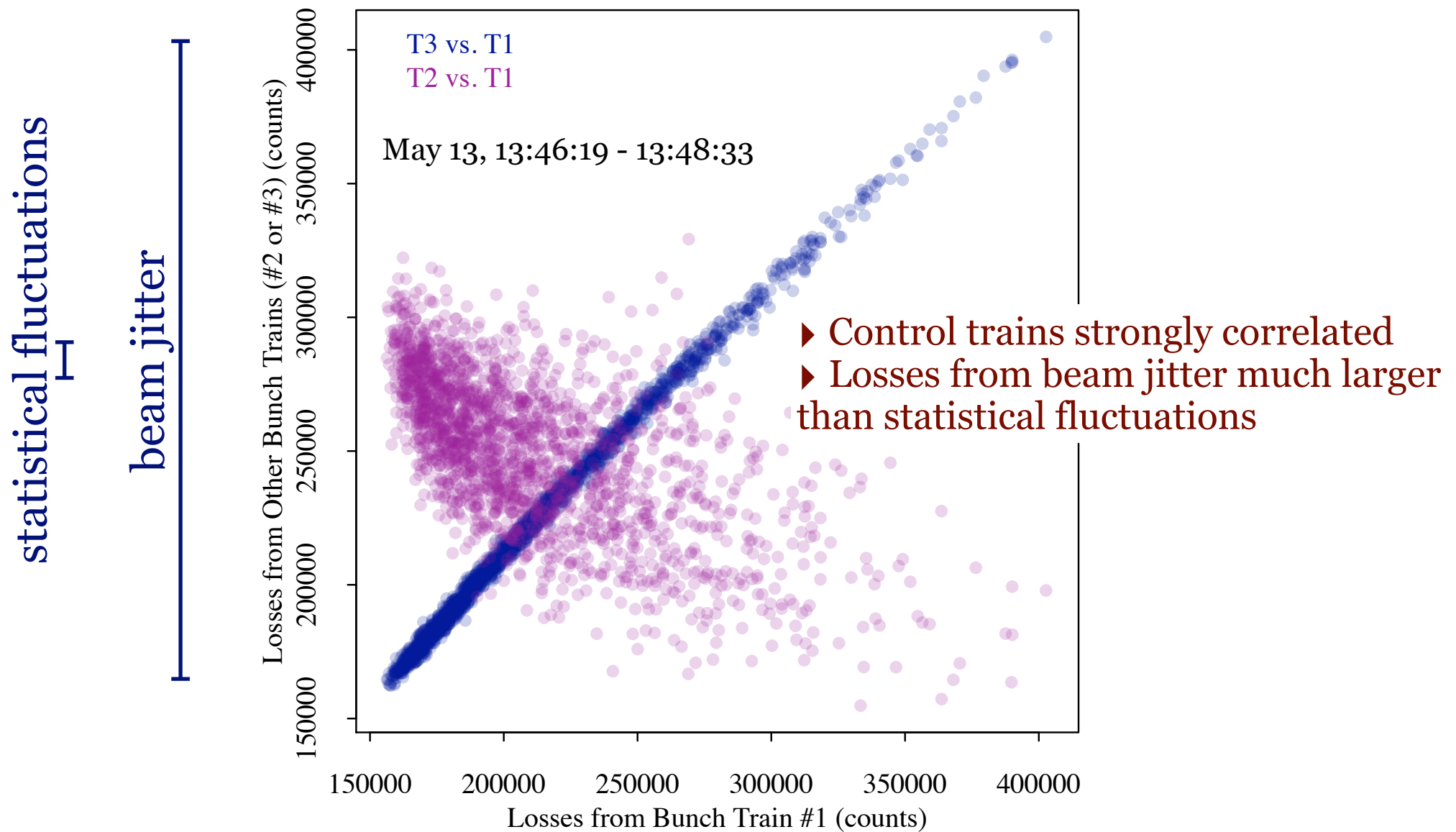
Example of **vertical collimator step out**,  $50\text{ }\mu\text{m}$



# Fourier analysis of losses



# Correlation of steady-state losses



- ▶ Hollow beam eliminates correlations among trains
- ▶ Interpretation: larger diffusion rate, lower tail population, less sensitive to jitter

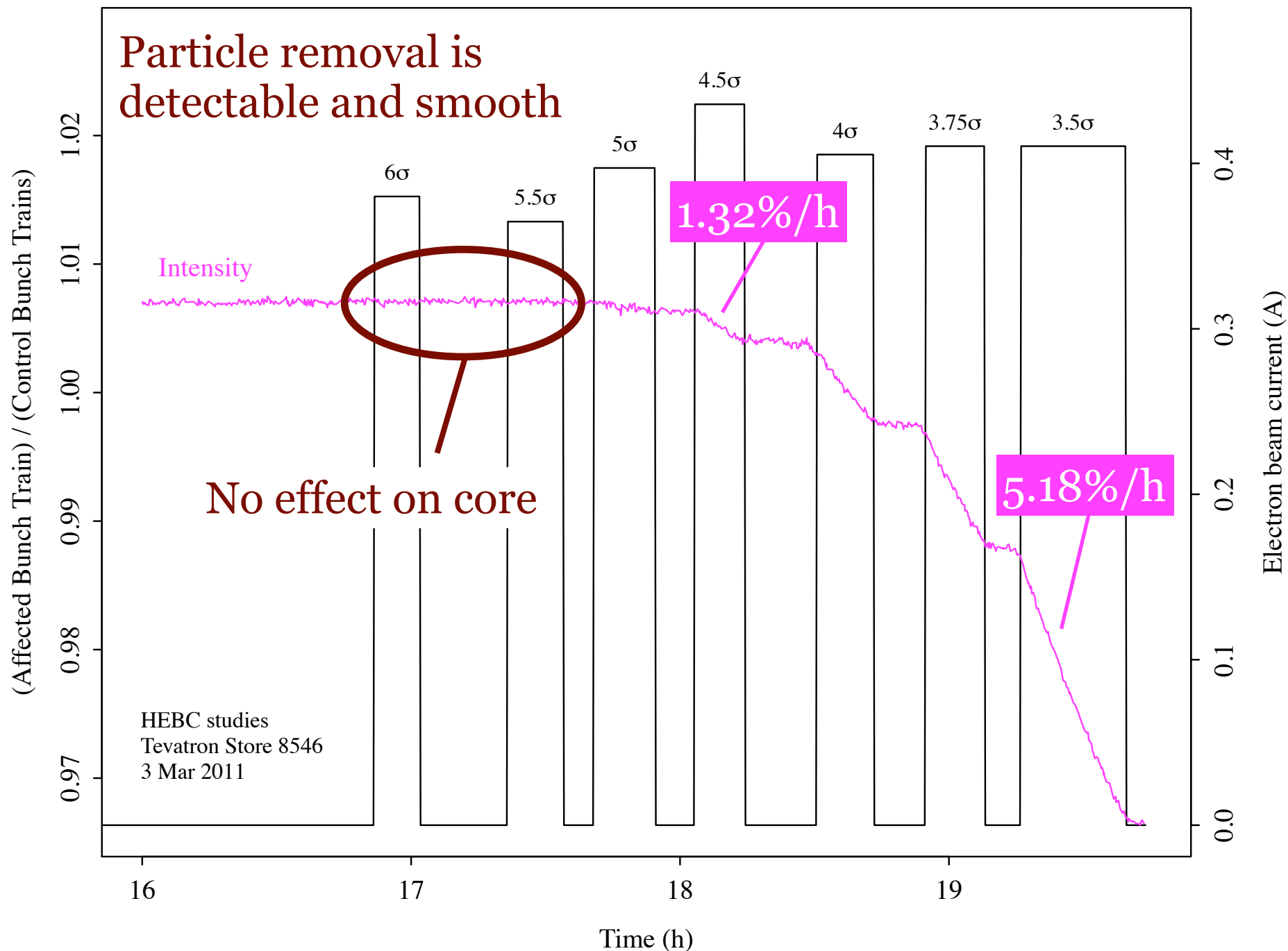
# Summary and outlook

- ▶ Scraping with hollow electron beams appears to be a viable option for storage rings and colliders
- ▶ Many new observations at the Tevatron: halo removal rates, effects on core, diffusion, fluctuations in losses, collimation efficiencies, ...
- ▶ First results will appear in Phys. Rev. Lett. (arXiv:1105.3256)
- ▶ A few more studies planned (now - end of August)
- ▶ New 1-inch gun assembly and test in September (A. Didenko, contractor engineer)
- ▶ Validate Tevatron simulations (I. Morozov, guest scientist)
- ▶ TEL2 hardware (2 M\$) will become available after Tevatron shutdown
- ▶ Transfer experimental program to CERN? Support from DOE LARP Review and LHC Collimation Review (June 2011).
- ▶ Study applicability to LHC in collaboration with CERN: needed? feasible? (V. Previtali, new Toohig fellow). Possible key improvements: scraping before collisions and collimator setup, efficiency for ions.

*Thanks for your attention*

# Backup

# Removal rate: affected bunch train relative to other 2 trains



# Is the core affected? Are particles removed from the halo?

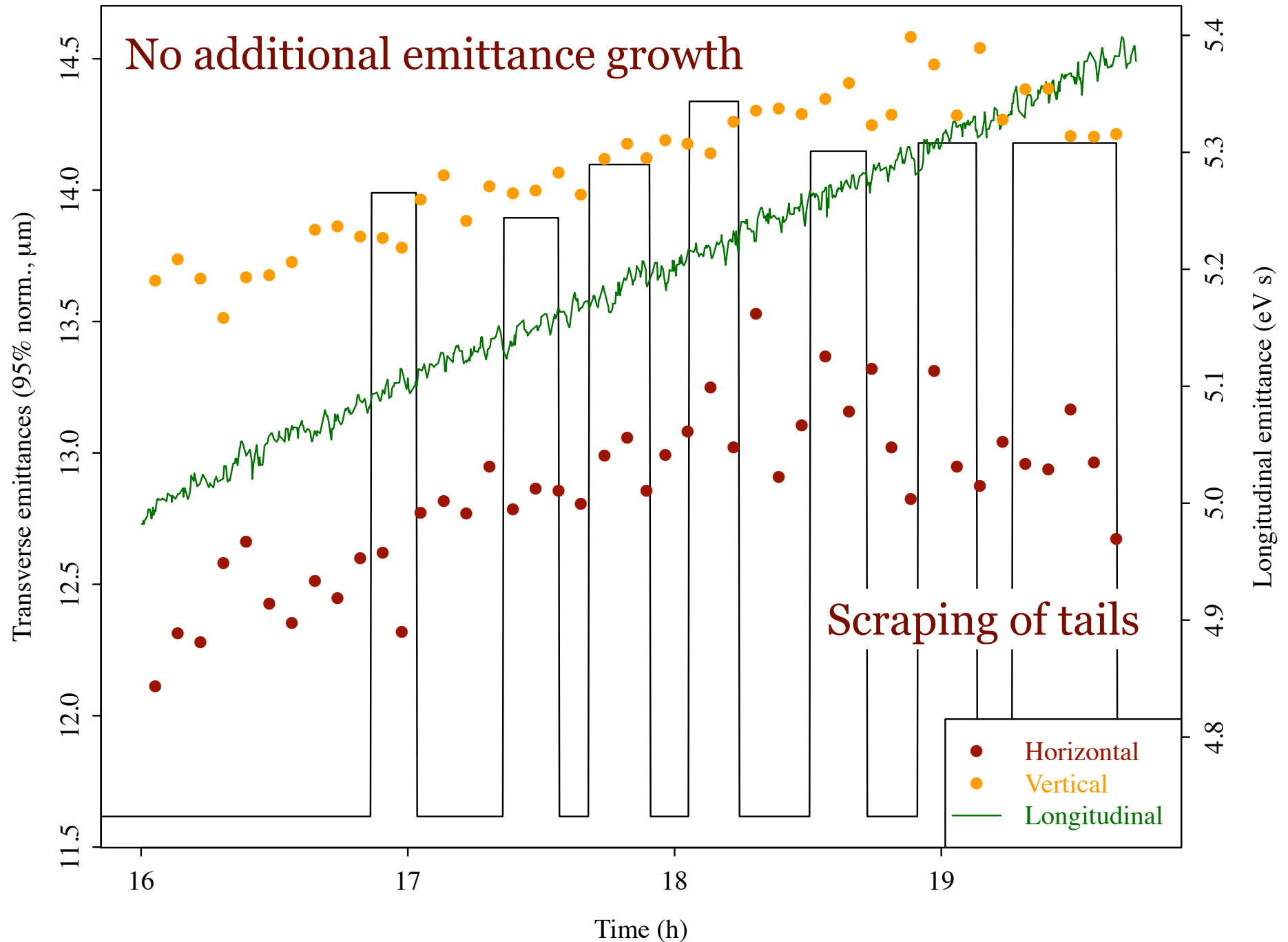
Several strategies:

- ▶ **No removal** when e-beam is shadowed by collimators (previous slide)
- ▶ Check **emittance** evolution
- ▶ Compare **intensity** and **luminosity** change when scraping antiprotons:

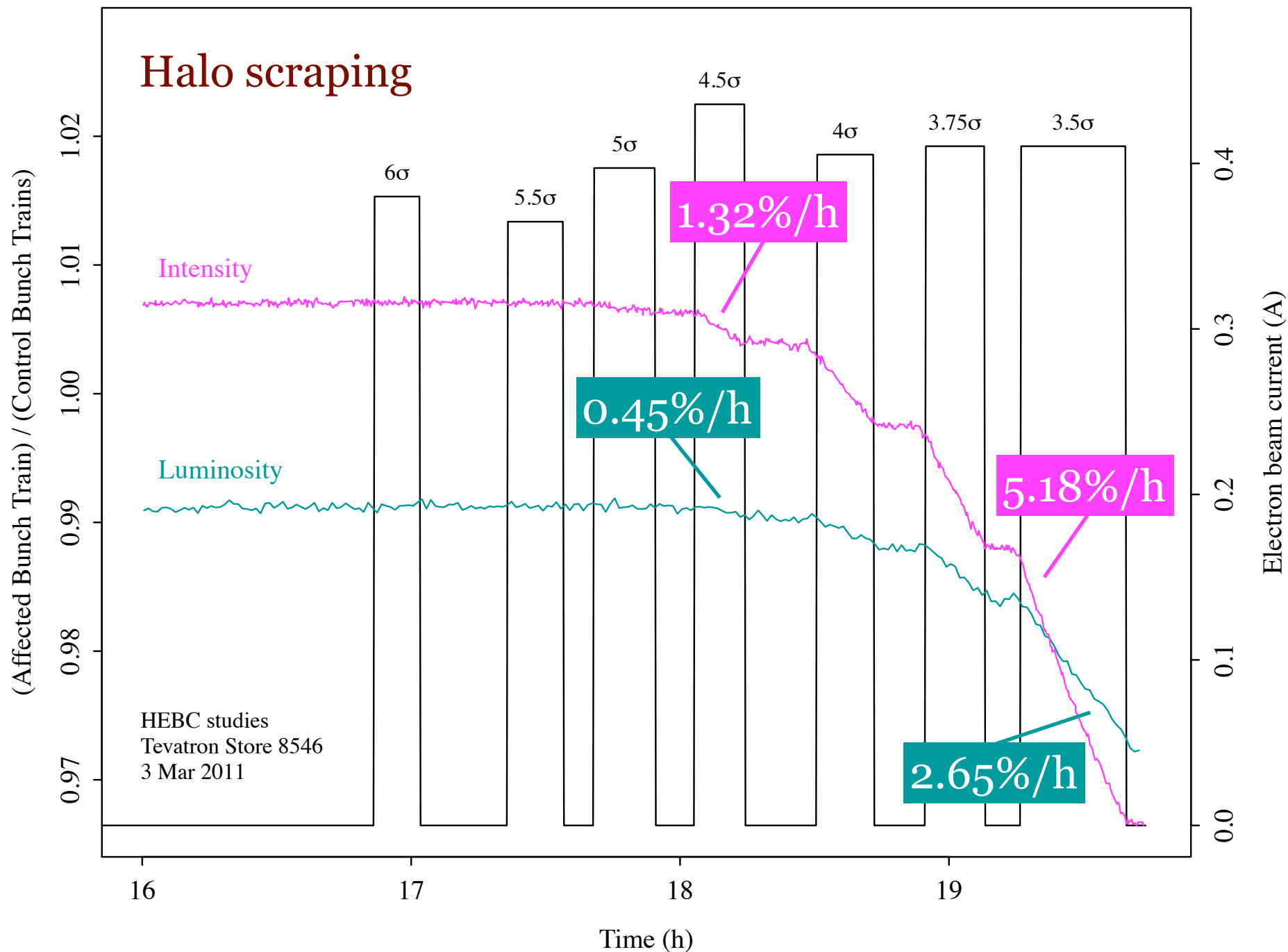
$$\mathcal{L} = \left( \frac{f_{\text{rev}} N_b}{4\pi} \right) \frac{N_p N_a}{\sigma^2} \qquad \frac{\Delta \mathcal{L}}{\mathcal{L}} = \frac{\Delta N_p}{N_p} + \frac{\Delta N_a}{N_a} - 2 \frac{\Delta \sigma}{\sigma}$$

- ▶ same fractional variation if other factors are constant
- ▶ luminosity decreases more if there is emittance growth or proton loss
- ▶ luminosity decreases less if removing halo particles (smaller relative contribution to luminosity)
- ▶ **Removal rate** vs. amplitude (collimator scan, steady state)
- ▶ **Diffusion rate** vs. amplitude (collimator scan, time evolution of losses)

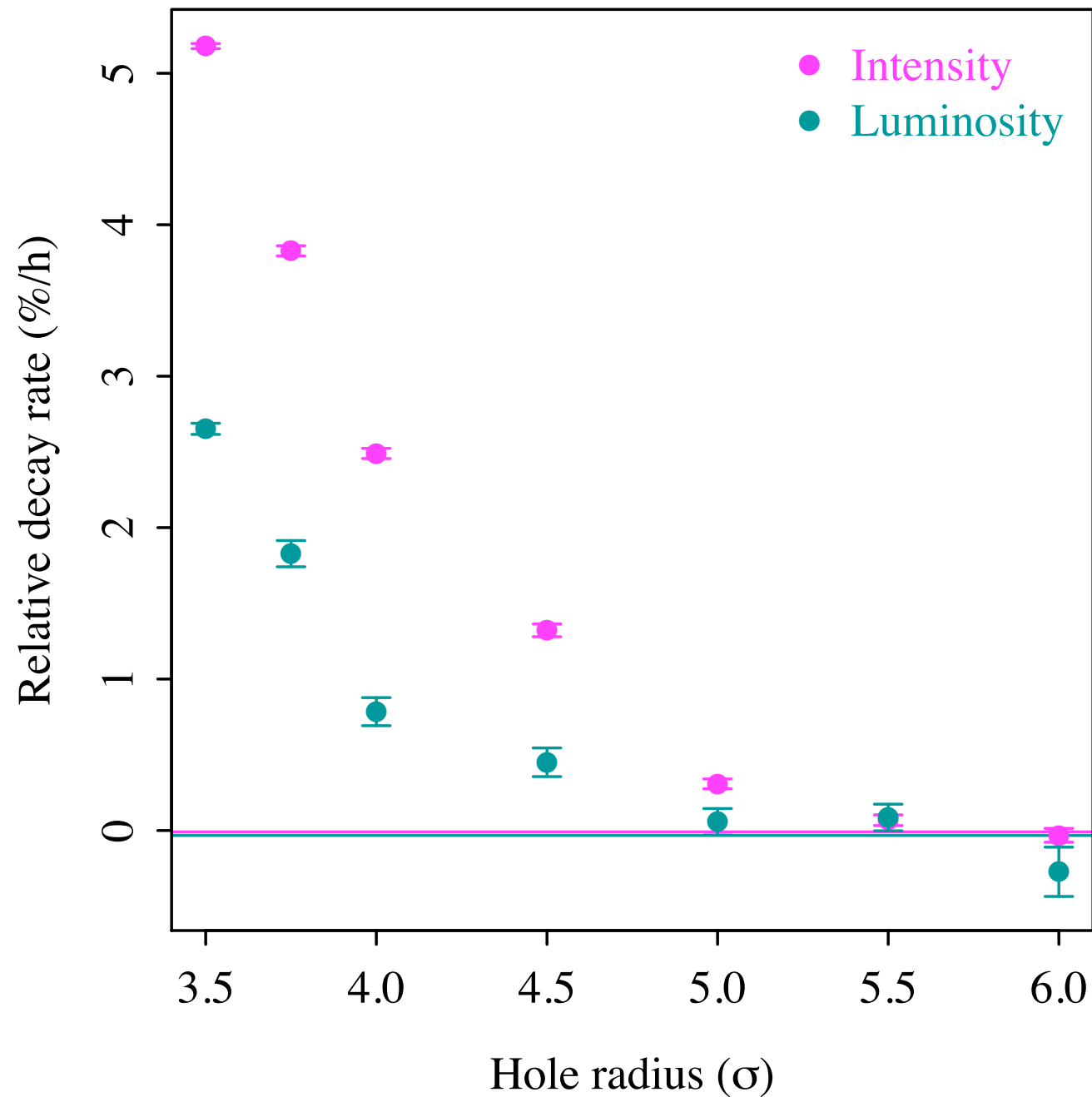
# Emittances of affected bunch train



# Luminosity of affected bunch train relative to other 2 trains

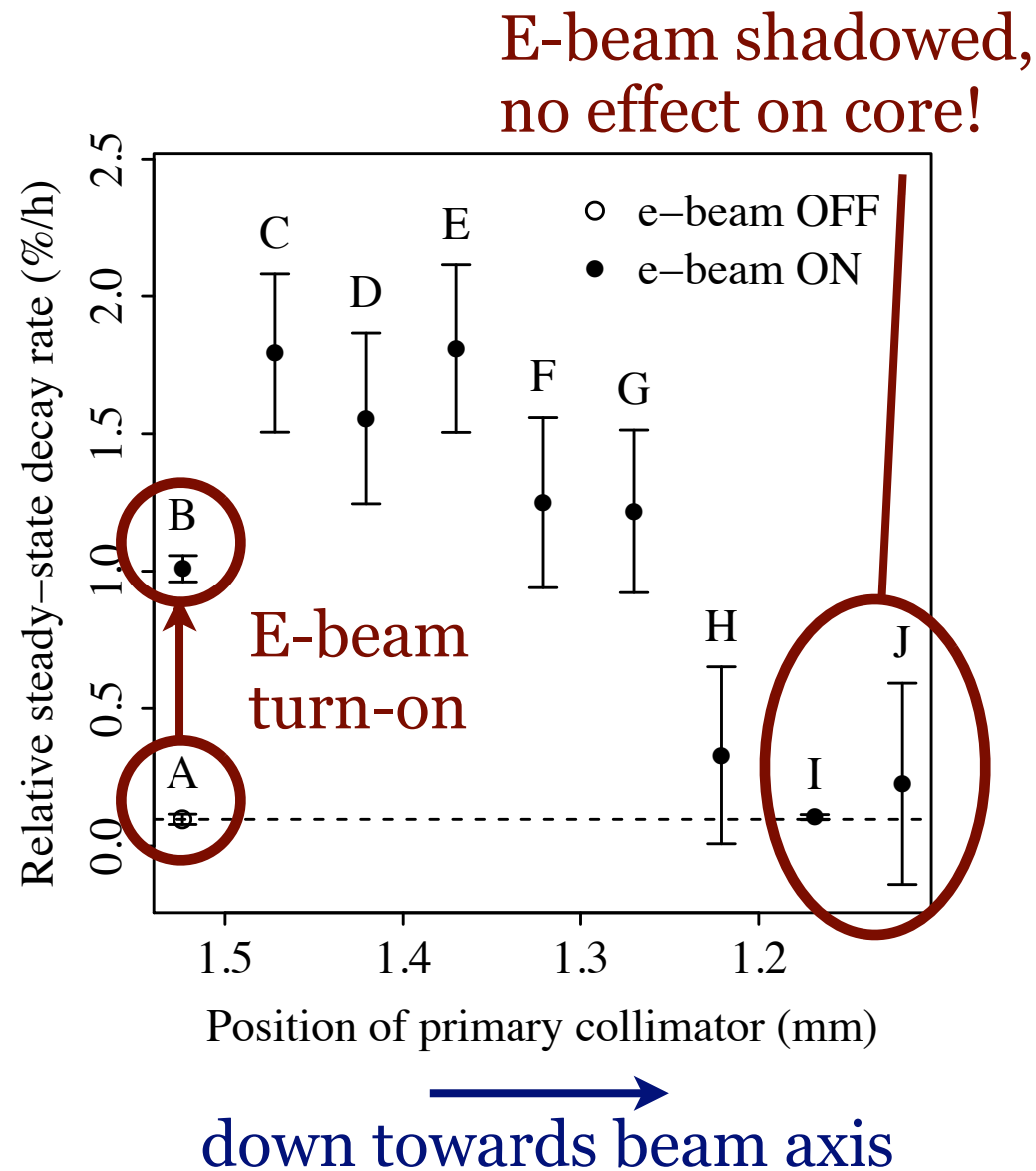
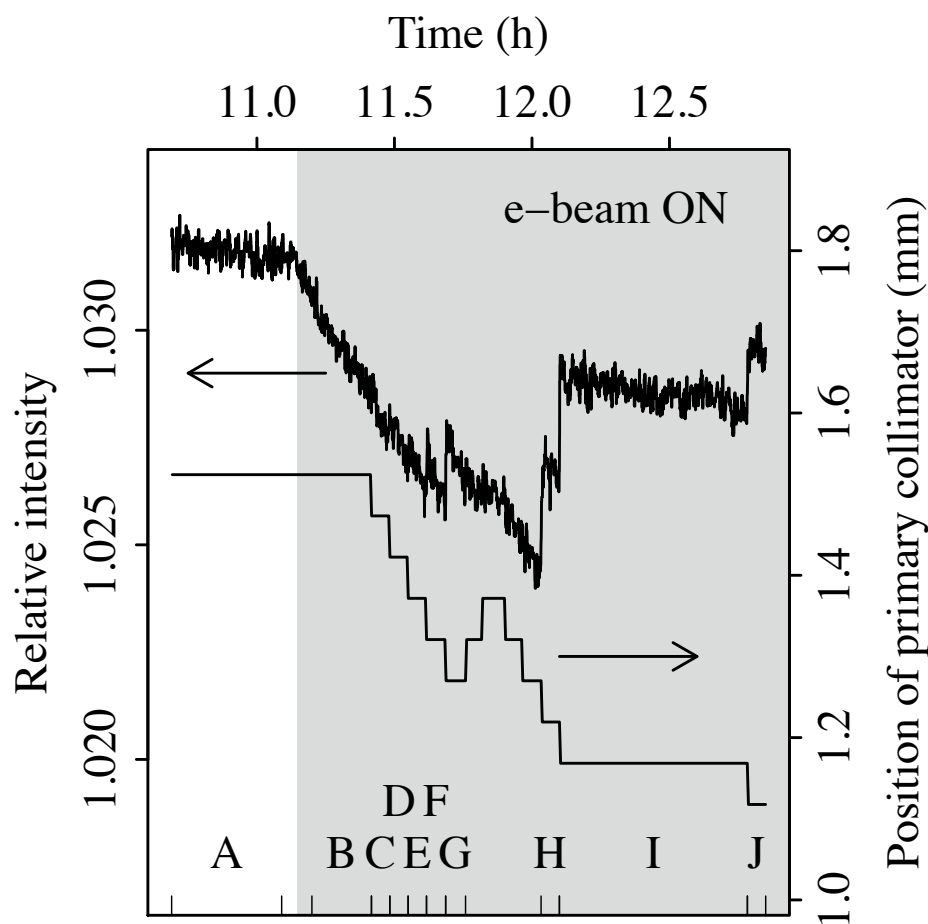


# Relative decay rates



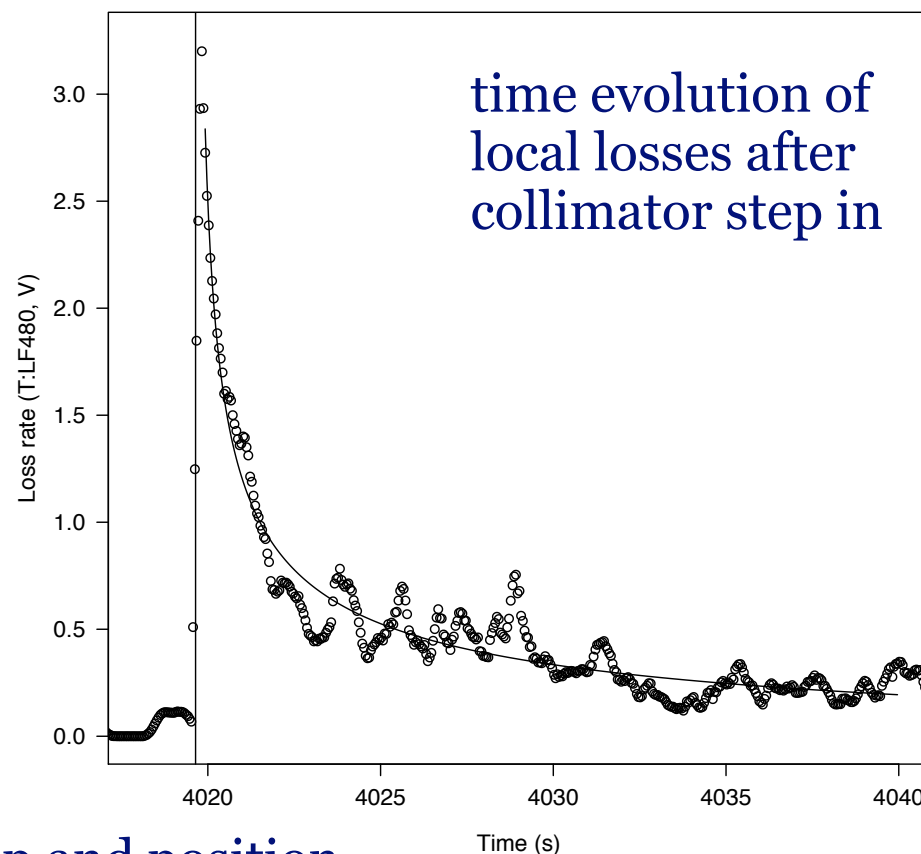
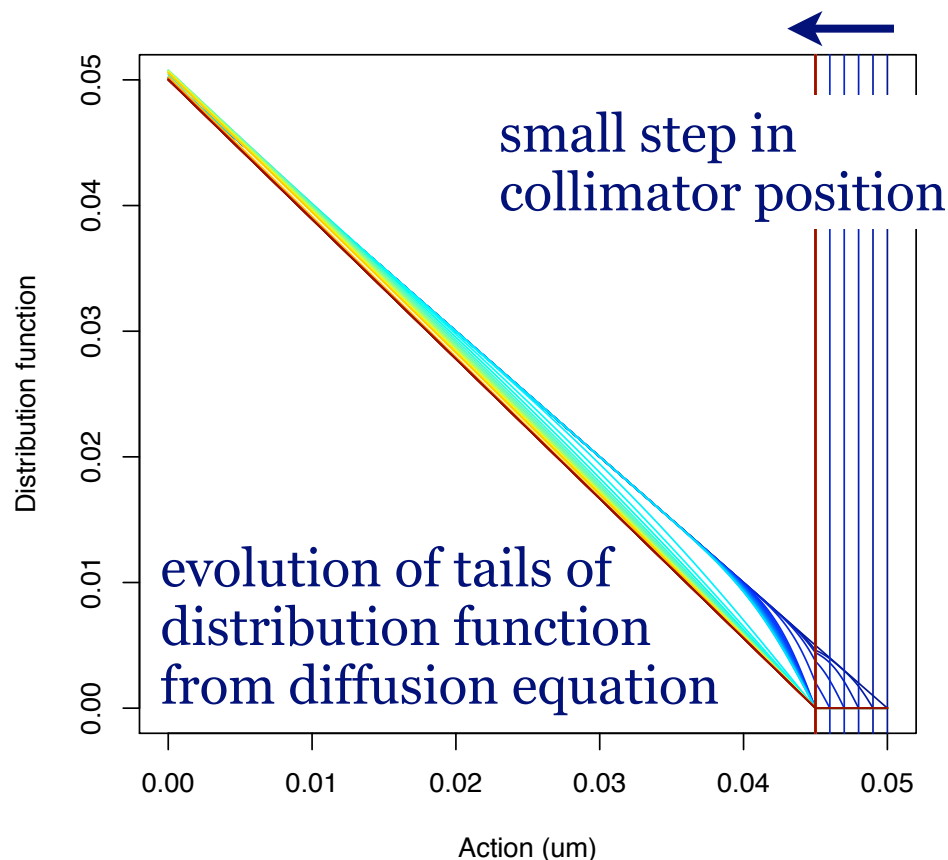
# Removal rate vs. amplitude from collimator scan

Electrons (0.15 A) on pbar train #2,  $3.5\sigma$  hole (1.3 mm at collimator)  
Vertical scan of primary collimator (others retracted)



# Diffusion rate vs. amplitude from collimator scans

Mess and Seidel, NIM A **351**, 279 (1994)



observed loss rate

collimator step and position

background

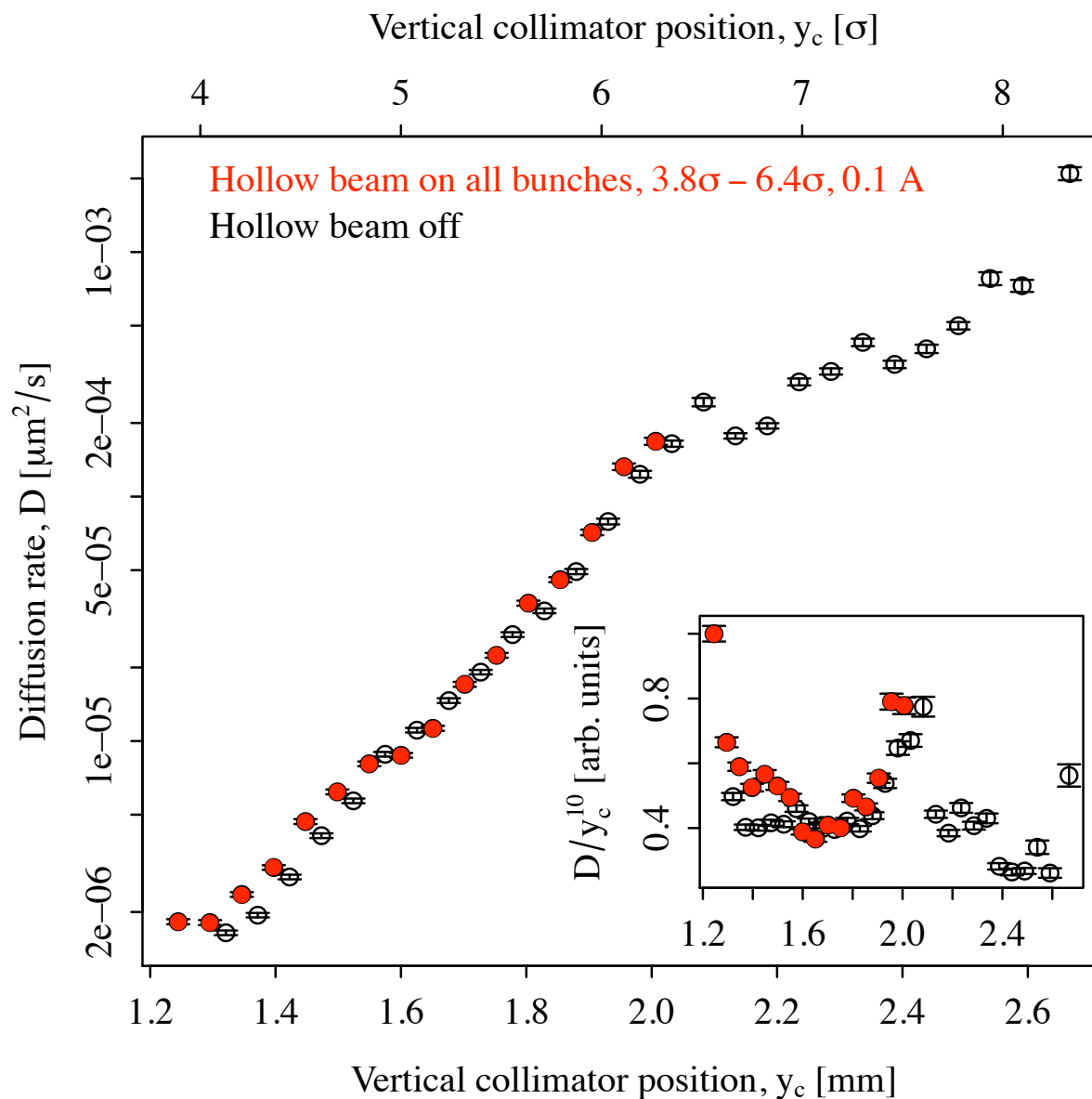
$$L(t) = a_1 \left\{ 1 + \frac{|\Delta x_c| / x_c}{\sqrt{\pi R(t - t_0)}} \right\} + a_0$$

normalization (intensity, efficiency, ...)

parameter related to diffusion rate

$D = R \cdot x_c^4 / \beta_c^2$

# Diffusion rate vs. amplitude - preliminary



- First measurement of diffusion rates in Tevatron
- Effect of e-lens is detectable, but need gated loss monitors

# New gated antiproton loss monitors

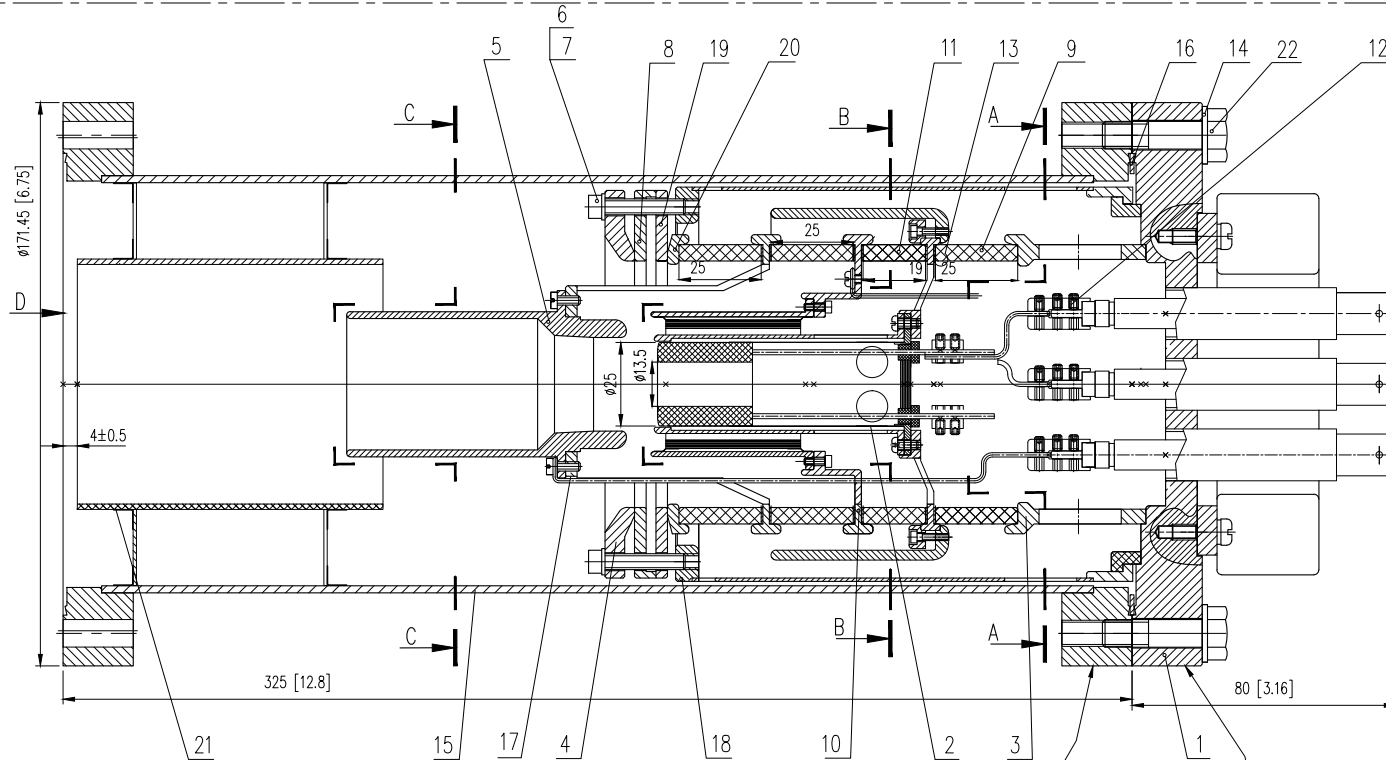
- ▶ Scintillator paddles installed near F49 antiproton absorber
- ▶ Gated to individual bunch trains
- ▶ Logged at 15 Hz



For simultaneous measurements of **diffusion rates**, **collimation efficiency**, and **loss spikes** on affected and control bunch trains at maximum electron currents

# Design of larger (1-inch) hollow gun

- ▶ 25 mm outer diameter, 13.5 mm inner diameter
- ▶ Up to 3 A at 5 kV



- ▶ Goal: To test technical feasibility
- ▶ Characterization in Fermilab electron-lens test stand (September?)
- ▶ Installation in Tevatron unlikely